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IMPACT ON A UTILITY, UTILITY CUSTOMERS AND THE ENVIRONMENT OF AN ENSEMBLE OF SOLAR DOMESTIC HOT WATER SYSTEMS

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ABSTRACT: The benefits of the installation of a large number of solar domestic hot water (SDHW) systems are identified and quantified. The benefits of SDHW systems include reduced energy use, reduced electrical demand, and reduced pollution. The avoided emissions, capacity contribution, energy and demand savings were evaluated using the power generation schedules, emissions data and annual hourly load profiles from a Wisconsin utilitity. It is shown that each six square meter solar water heater system can save annually: 3560 kWh of energy, 0.66 kW of peak demand, and over four tons of pollution.

1. INTRODUCTION:

The peak load that a utility experiences usually occurs in the afternoon on the third or fourth consecutive day of hot sunny weather, due to large electric air conditioning loads. The key to solar domestic water heating for summer peak clipping is the coincidence of the utility's peak load days and the sunniest, hottest days, when solar systems perform best. Over one third of Wisconsin utilities do not have natural gas [1]. In these areas, most systems are electric, thereby having good SDHW potential.

Previous studies have looked at SDHW systems as only energy saving devices, using only average daily water usage statistics. To accurately evaluate demand reduction, hourly water draw values must be obtained. If an electric water heater has a 4.5 kW element that is either on or off, then the peak demand of one system is 4.5 kW. But, when many systems are averaged, the resultant peak demand is significantly lowered because the heating element demands are not concurrent. In addition to energy and demand reduction, other advantages of SDHW systems being explored are utility emissions reduction and contribution to utility generating capacity.

2. WATER DRAW:

The magnitude and timing of individual residential hot water draws are needed to evaluate the impact of many DHW systems on a utility. To circumvent monitoring and/or estimating problems, a water use simulation program, WATSIM, based on metered data and survey results, but with extended demographics and probabilities, was employed. WATSIM was developed by the Electric Power Research Institute (EPRI) and contains algorithms based on metering experiments, previous research, and statistics [2].

Up to three hundred sets of "different" household profiles may be created with WATSIM, while up to nine hundred sets of "different" customer profiles are achievable with some manipulation outside of the main program. Unfortunately, inconsistencies within WATSIM cast doubts upon the actual randomness (diversity) that it creates. A large enough sample size should produce a relatively smooth average profile. The average of three hundred customer households shows some "spikiness". Is a sample size just too small? To test this, the average of nine hundred households for five different days of the week with 10 differentrandom seed are shown in Figure 1.

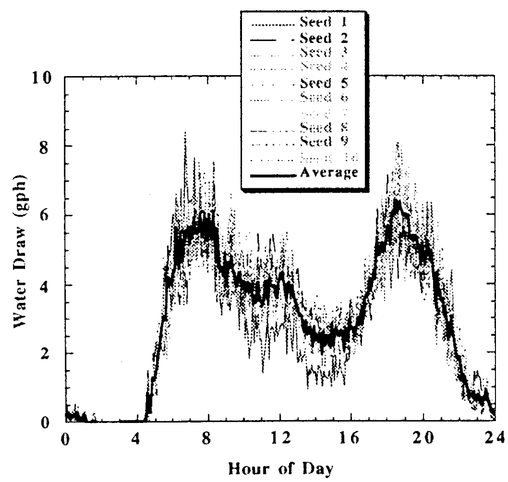

Fig. 1 WATSIM Tuesday draws showing the average of 900 customers using 10 random seeds

It is clear that a large number of WATSIM hot water draws are not truly independent. If the individual hot water draw profiles from WATSIM were used in TRNSYS [3] to model the diversified electrical demands of different DHW systems, the statistical problems would carry over into the electric utility impact analysis. Consequently, individual WATSIM hot water draw profiles were not used directly.

Average weekday and weekend-day loads can be derived from WATSIM that agree with other accepted metered and utility produced average hot water loads. The nine hundred "spiky" averages for ten different random seeds, (for five different weekdays and two different weekend-days) were "smoothed" to yield the weekday and weekend-day average hot water draws (in ten minute intervals) in Figure 2.

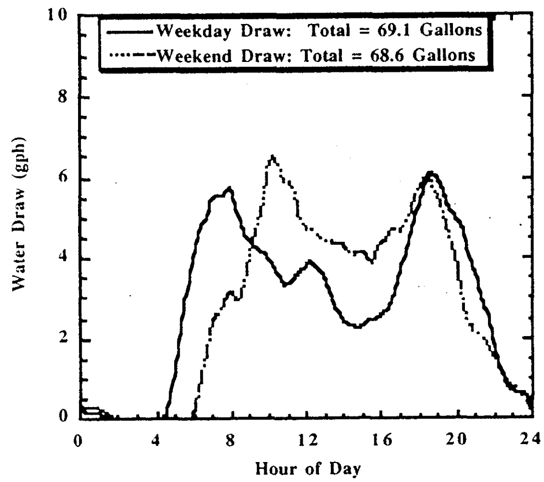

Fig. 2 WATSIM derived average water draw profiles

Although diversified average hot water draw profiles for weekdays and weekends have been obtained from WATSIM, modeling a single system with an average water draw does not produce the demand reduction achieved through a large number of varied, individual profiles, due to the on/off behavior of electric domestic water heaters. To evaluate the demand, energy, and emission reduction for a large number of solar domestic water heaters, it was originally thought that 100 to 1000 representative draws would have to be simulated on an annual basis. Such an analysis would have required about one year of computational time.

Using TRNSYS, the electrical load for an average water draw profile can be simulated with the same tank characteristics as for a typical 4.5 kW on/off electric water heater, but with one modification: the heating elements are removed and replaced by an energy rate controlled "zip heater". Both one and two-tank solar DHW systems were modelled. A one-tank model (with a heater that is one third of the way down) can be modeled with a storage tank of approximately 67% for storage of solar energy and the remainder electrically heated. In this application, a zip heater replaces the element that is normally in the upper one third of the tank. For the two-tank system, the zip heater, with the appropriate thermal losses, replaces the second tank.

To test the ability of the zip heater approach to represent the behavior of an ensemble of DHW and SDHW systems, TRNSYS simulations were performed for many hundreds of individual homes, (in each test of 100 homes the same solar system was used; only the water draw was varied). The average results of these simulations were compared to the results (both in magnitude and time) of a system using an average draw and a zip heater. The magnitude and timing of the energy are essentially the same. The comparisons were repeated for various SDHW designs with the same conclusion. The zip heater method significantly reduces computation time, and it allows the user to experiment with a range of water draw profiles, various tank sizes, and different utility loads easily and without the necessity of knowing the details of the thousands of individual water draws.

3. <u>UTILITY CONSIDERATIONS:</u> Utilities use various forms of power generation to meet the system load, beginning with the plant with the lowest operating costs. Each of these plants incurs a certain cost to the utility and to the environment. Coal, oil, and natural gas plants release varying levels of carbon dioxide, sulfur dioxide, oxides of nitrogen, methane and particulates.

The pollution abatement benefits of SDHW systems can be quantified into $/ton. By not considering the environmental cost of airborne pollutants, utilities monetize them, as $0/ton. There is much debate over what price to put on which pollutants. The actual amount of pollutant avoided through solar DHW systems can be evaluated while the price that regulators or society place on avoided pollution is extremely uncertain.

Table 1: MONETIZATION OF POLLUTANTS

Costs Per Ton of Airborne Emissions			
Pollutant	**PSCW**	**Mid-Range**	**High**
Carbon		$26	*
CO_2	$15.64	$15-$18	$26.45
SO_2	$250	$170 -$2000	$4006
N_2O	$2814.7	$2700	*
NO_X		$400-$1640	$7934
CH_4	$156.38	$150	*
Particulates		$2380	*

* Unavailable, CO_2: $26.45 [4], SO_2: $2000 =EPA fine, $1873/ton for SO_2 [4] $4006/ton [5], NO_2: $2700 [5], NO_X: $400/ton [6], $7934 [4], Particulates: $2380 [5]

Table 1 shows a range of values placed on avoided pollutants (Public Service Commission of Wisconsin, mid-range, and high) from various published sources,. The means by which those numbers were produced are varied. Of course, the minimum values are all zero. These values are used later in the economic analysis.

To calculate the impact of solar DHW systems on a utility, an hourly utility load profile for a representative year must be analyzed. The weather is a driving force for most utility peaks. Typical Meteorological Year (TMY) weather data cannot be used: a hot week that produces the utility peak demand may be a rainy week for the TMY weather. 1991 is considered a representative year for Wisconsin utilities and was used throughout this study.

Figure 3 shows how the August load directly follows the ambient temperature. While the peak temperature occurred on Monday, the peak utility demand occurred on Thursday, August 29th, due to electric air conditioning loads on the fourth of four consecutive hot, sunny days. This behavior is thought to be representative of all summer peak periods for all utilities.

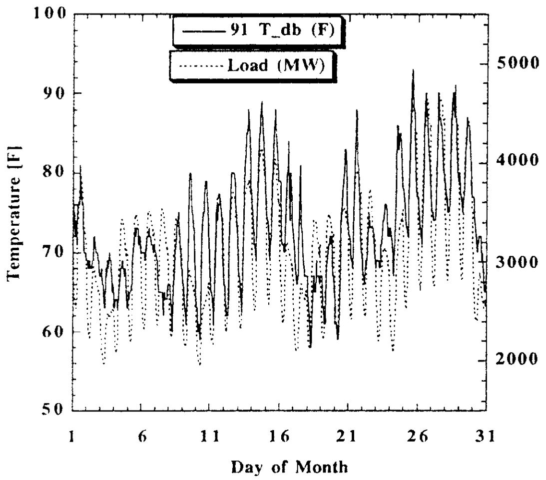

Fig. 3 Aug. 1991 Milwaukee temperature and WEPCO load

The methodology most utilities use to dispatch different power plants is the least cost production model. Using the least cost order the marginal plant is known and the correspoding costs and pollutant generation can be estimated. If the corresponding hourly (or shorter) DHW and SDHW demands are known, it is then possible to predict the costs and emissions reduction resulting from the operation of each SDHW system. The evaluation also requires knowledge about the maintenence periods and forced outages statistics. For example, if the nuclear plant at WEPCO's Point Beach site were down for maintenance, the worst cost and pollutant scenario would be in effect, because the more expensive and more polluting coal plants would be dispatched to meet the load.

4. COST PERSPECTIVE: Two distinctly different perspectives of the costs and benefits of large scale replacement of conventional DHW systems with SDHW systems are analyzed. Solar DHW systems can be analyzed from both the utility and consumer viewpoints. Both analyses consider lifetime energy, demand, emission, and capacity considerations.

The traditional approach for evaluating solar energy system savings is to compare owning and operating costs with fuel savings. Yet, since solar DHW systems provide not only energy, (and a large number of them could be considered a "diversified solar thermal power plant"), they also contribute to pollution and demand reduction. Analyzing solar DHW systems from a supply-side perspective gives the solar DHW systems credit for providing energy and capacity, while reducing utility demand and emissions.

To properly analyze the benefits of solar, the marginal cost perspective needs to be supplemented with a lifetime cost analysis (which includes initial and O&M costs). For this analysis, the life cycle cost of the solar DHW systems, including the value of contribution to meet the peak referenced to a combustion turbine (the last unit added) and all remaining costs need to be normalized (divided by the energy use) for a fair comparison [7].

For the customer perspective cost analysis, the solar DHW systems are initially purchased by the utility and paid for by the customer over the system's life. The most significant barriers to customer purchases of SDHW systems are high initial costs and technological uncertainty. Utility involvement in a large-scale solar DHW program can circumvent both problems. Utilities have been giving rebates for energy savings options for many years. Some utilities are also giving credit for peak demand reduction and avoided energy costs. A utility rebate coupled with a financing program in which the cost of the solar system is added to monthly bills in installments brings the perceived high cost of solar DHW systems to a reasonable level. Also, the utility involvement and the large number of system installed throughout the community help alleviate customer uncertainties about reliability.

5. RESULTS: Variations of three differently sized solar systems were compared with a typical electric DHW system (52 gallons, 4.5 kW electrical resistance heating elements, EF= 0.87).

5.1 DHW Comparison Systems: Three collector area/-storage tank size combinations were considered for both one and two tank systems. Systems used either a conventional thirty watt pump or a photovoltaic powered pump. Systems S1, S2 and S3 had 4, 6 and 8 square meters of collector, respectively; systems B were all one tank systems.

Annual electrical energy requirements for the twelve solar DHW systems and the conventional electric DHW system are compared in Figure 4. As expected, the systems with the largest collector areas, have the least annual energy requirements. The monthly energy requirements of the "best" (S3B:PV) and "worst" (S1:30W) solar DHW systems are compared with the conventional electric DHW systems in Figure 5.

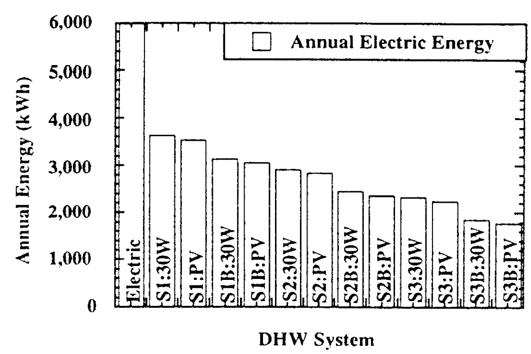

Fig.4 Annual electricity requirements of DHW systems

From the dispatch order, the gas combustion turbines were operated 497 hours, peaking coal plants (Coal 3) were at the margin for 3735 hours, intermediate coal plants (Coal 2) were at the margin for 3951 hours, and base load coal plants (Coal 1) were at the margin for only 577 hours of the year.

This particular Wisconsin utility has a very high coal dependence. The impacts of the best and worst solar DHW systems are compared with the conventional electric system for the different operating periods in Figure 6. Solar DHW systems provide significant energy savings during all marginal plant operation, except base coal and nuclear plants. The solar system impacts during coal plant operation result in significant emission reduction.

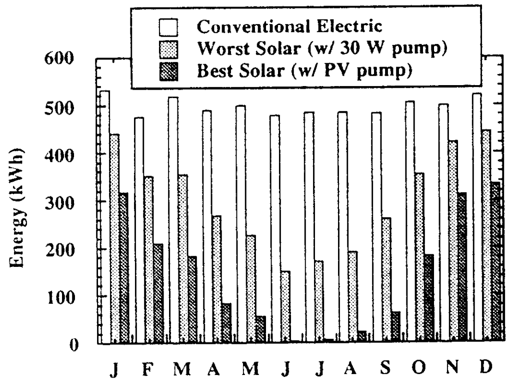

Fig. 5 Monthly energy requirements for DHW systems

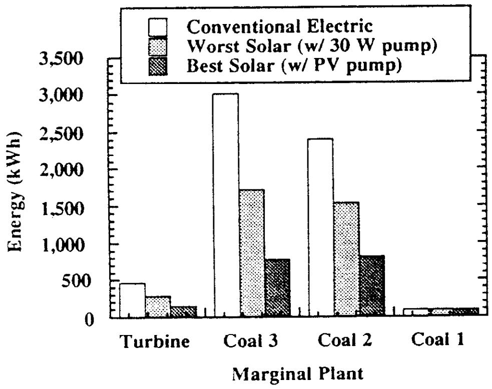

Fig. 6 1991 WEPCO annual energy reduction

5.2 Peak day demand reduction: Due to electric air conditioning loads, most U.S. and Wisconsin utilities experience their highest demands in the summer. Fortuitously, solar system peak performance coincides with utility peak demand. Figure 7 shows the WEPCO load, the average load from conventional electric DHW systems and the average load from the best and worst SDHW systems for the 1991 peak day.

The difference between the solar DHW and conventional DHW demands is termed the "peak demand reduction" of the solar system. The value to the utility for these peak demand reductions can be significant. The Wisconsin Center for Demand-Side Research lists the value for demand reduction to Wisconsin utilities as $72.97 per kW per year [1]. Thus, for a 15 year life and no discounting, the value of peak demand reduction is over $1000 per kW.

The systems with the highest demand reduction are the one-tank systems with PV pumps. The one-tank systems with 30 watt pumps have the next largest peak demand reduction. Even the two-tank systems with PV pumps had higher peak demands than the one-tank systems with 30 watt pumps. Thus, electrical demand from the constant losses from the electric back-up tanks exceed the electric pump demand. Additionally, if the tanks are inside, the losses add heat to the house which put a larger load on electric air conditioners in the summer. Tank configuration appears to be more important than parasitic power. Again, the two-tank configuration provides an upper limit for solar system demand due to the zip heater model with constant losses.

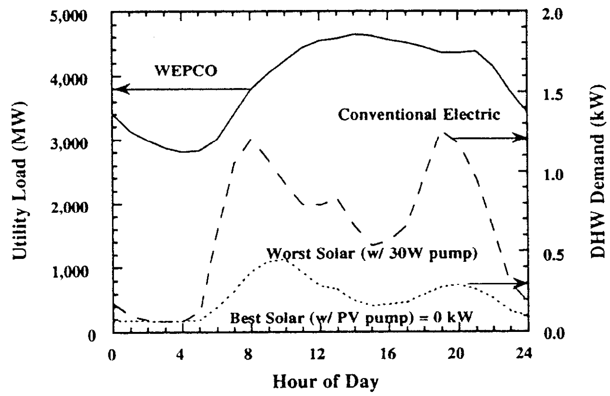

Fig. 7 WEPCO peak day DHW demand comparison

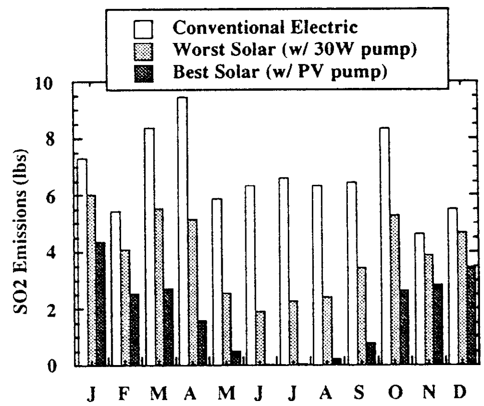

Fig. 8 1991 WEPCO sulfur dioxide emissions

5.3 Annual and monthly emission savings: While the societal costs for various pollutants are a subject of debate, the actual amounts of pollutants avoided through solar DHW system replacement are only dependent on characteristics of the marginal power plant. As a specific example including all pollutants, each six square meter solar water heating system can save annually: 3559 kWh of the energy, 0.66 kW of peak demand, and over four tons of pollution (7727 # CO_2, 51 # SO_2, 0.11 # N_2O, 17 # NO_X, 0.13 # CH_4, and 1.1 # particulates) for WEPCO. (Based on 5928 kWh annual energy requirements of a conventional 52 gallon electric system resulting in over six tons of airborne pollutants: 12705 # CO_2, 80.78 # SO_2, 0.180 # N_2O, 28.35 # NO_X, 0.200 # CH_4, 1.820 # particulates.). Figure 8 shows the sulfur dioxide emissions from DHW and the best and worst SDHW systems.

5.4 Cost analysis results: The cost analysis compares the utility cost (in $/year and $/kWh) for each power plant. The cost perspective evaluates all utility costs associated with the purchase and operation of the best available technology for electric power production. The two baseload plants, two intermediate load plants, and one peaking combustion turbine were chosen for comparison with the "diversified solar plant". All plant information was obtained from the Public Service Commission of Wisconsin [8]. All new technologies were considered to operate at the EPA New Source Performance Standards for emission production [9].

The costs per unit of energy produced ($/kWh) of the new technologies were compared (with zero emission monetization) to the solar DHW values considering zero credit for emission reductions, credit for PSCW emission savings, and high value solar emissions savings as shown in Table 1. The various levelized costs are shown Table 2 (The lifetime for solar systems was 15 years, while new technology lifetimes were 30 years. Solar systems were given maintenance costs of $25/year).

The first unit electricity cost result ($/kWh) does not penalize the new technologies for their emissions, neither does it give credit to the "diversified solar plants" for their emission reductions. The second and third listed unit electricity costs ($/kWh) consider the unit cost of the new technologies without monetization, yet give the "diversified solar systems" the emission savings that they actually incurred with the marginal emissions reduction analysis based on the least cost production model. The solar credits were given for the PSCW and high emission monetization values from Table 1.

Five of solar DHW systems "provide energy" at a cost to the utility that is less than the associated cost for a new technology combustion turbine ($0.06/kWh) even without credit for emission reduction. When the diversified solar systems are given credit for their emission reductions (at the PSCW monetization levels), all but one of the solar systems are competitive with the a new gas combustion turbine, five SDHW systems are less expensive than an intermediate coal plant, with two solar systems less expensive than the baseload plants! When the highest published emission monetization values are used to credit the solar systems, all of the solar systems are significantly less expensive than the baseload plants, and six SDHW systems actually "save" the utility money per each kWh produced over its lifetime!

5.5 Customer Perspective Cost Analysis: A monthly bill impact analysis was performed for each of the twelve solar DHW system variations. The cost analysis was performed under the assumption that the utility purchases the solar systems for the customers and the customers pay back the utilities for the systems through their monthly electric bills over the course of the systems' lifetime. The customer utility bill impact analysis demonstrates the positive or negative cash flow that the customers would see in their monthly statements.

Many scenarios for possible utility rebates based on avoided generation costs, peak demand reduction, and emission monetization were considered. The results for the twelve solar DHW systems are shown in Table 3 for the base case (with no utility incentive) and three rebate scenarios,. A positive monthly bill impact ($/month) represents a reduction in the customer electricity bill, and a negative monthly bill impact represents an increase in the customer electricity bill. Without any rebates, three one-tank systems provide the customer with a positive monthly cash flow. With a utility rebate for demand reduction, nine of the twelve solar DHW systems provide positive customer electric bill impacts. Two of the two-tank systems with PV pumps had negative monthly bill impacts, even with a modest rebate.

When multiple utility rebates for peak demand reduction, avoided generation costs, and emission reductions were given, all SDHW systems provided positive monthly cash flows for the customer,. The single-tank systems (designated "B") provide greater savings than their equivalent two-tank models. The slightly higher peak demand reduction rebates, avoided generation rebates, and emissions credits for PV pumped systems (compared to those of the 30 watt systems of equivalent size and tank configuration), did not outweigh the increased initial costs, due to their more expensive PV pumps ($500 more per system). The least expensive systems do not necessarily save the most money. The systems with the most energy savings are not more cost effective than other SDHW systems, and are often less so.

6. CONCLUSIONS

Solar DHW systems are found to be economically feasible from both a supply-side utility perspective and a customer monthly bill analysis. Photovoltaic poweered pumps do not appear to be as cost effective as conventional 30 watt pumps from either perspective, due to high initial costs. However, single-tank SDHW systems consistently performed better and were more economically attractive from both cost perspectives.

Solar DHW systems have significant economic and environmental potential in the state of Wisconsin. Since each utility's resource mix, weather, water mains temperatures and load profile have a very unique impact on emissions, energy and demand reduction, a proper analysis of SDHW potential REQUIRES utility specific data.

7. REFERENCES

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Table 2: Customer-Meter Unit Cost of Electricity

Plant Technology	Nominal Capacity	Plant Type	Capitol Cost	CCI Values	Total Costs Zero Ext.	Total w/ Zero	Total w/ PSCW	Total w/ High
	MW		$/kW	%	$/yr	$/kWh	$/kWh	$/kWh
Adv Nuclear-Passive	600	Base	1609	0.994	3.12E+08	**0.032**	x	x
IGCC	400	Base	1567	0.994	2.22E+08	**0.036**	x	x
Combined Cycle	200	Int.	694	0.994	1.29E+08	**0.046**	x	x
HAT Cycle	200	Int.	694	0.994	1.21E+08	**0.041**	x	x
WISC CT	83	Peak	323	0.994	6.41E+07	**0.060**	x	x
Solar 1 30W	0.000238	Renew.	2000	0.829	225.57	**0.072**	**0.052**	**0.006**
Solar 1 PV	0.000238	Renew.	2500	0.875	275.37	**0.089**	**0.070**	**0.024**
Solar 1B 30W	0.000202	Renew.	1800	0.946	205.65	**0.055**	**0.036**	**-0.010**
Solar 1B PV	0.000202	Renew.	2300	0.991	255.45	**0.071**	**0.051**	**0.006**
Solar 2 30W	0.000392	Renew.	2300	0.846	255.45	**0.052**	**0.033**	**-0.013**
Solar 2 PV	0.000392	Renew.	2800	0.885	305.25	**0.067**	**0.047**	**0.001**
Solar 2B 30W	0.000364	Renew.	2100	0.955	235.53	**0.042**	**0.022**	**-0.023**
Solar 2B PV	0.000364	Renew.	2600	0.994	285.33	**0.055**	**0.035**	**-0.011**
Solar 3 30W	0.000561	Renew.	3500	0.851	374.97	**0.066**	**0.046**	**0.000**
Solar 3 PV	0.000576	Renew.	4000	0.885	424.77	**0.077**	**0.057**	**0.011**
Solar 3B 30W	0.000561	Renew.	3200	0.96	345.09	**0.051**	**0.031**	**-0.014**
Solar 3B PV	0.000561	Renew.	3800	0.994	404.85	**0.064**	**0.044**	**-0.001**

Table 3: Customer Monthly Bill Savings

Bill Impact ($/month)	System Cost	NRG saved	Dmd Sav.	Base Case	Dmd Rebate	Avoided Gen.	Emission Credit PSCW	High	Average Savings
System	$	kWh	kW	$/mo.	$/kW-yr	$/yr	$/yr	$/yr	$/month
SYS2B:30W	2100	3142	0.630	**5.28**	9.89	12.31	11.83	27.12	13.29
SYS2B:PV	2600	3227	0.660	**1.81**	6.64	9.03	8.52	24.17	10.04
SYS3B:30W	3200	3735	0.630	**0.91**	5.52	9.18	8.56	26.40	10.11
SYS1B:30W	1800	2453	0.577	**2.24**	6.46	7.90	7.51	19.79	8.78
SYS2: 30W	2300	2674	0.563	**-0.14**	3.98	6.05	5.56	18.91	6.87
SYS3B:PV	3700	3816	0.660	**-2.60**	2.24	5.85	5.21	23.40	6.82
SYS1B:PV	2300	2538	0.607	**-1.23**	3.21	4.61	4.20	16.85	5.53
SYS2:PV	2800	2758	0.593	**-3.62**	0.73	2.76	2.24	15.95	3.61
SYS3: 30W	3500	3260	0.563	**-5.40**	-1.28	2.04	1.39	17.26	2.80
SYS1: 30W	2000	1955	0.465	**-3.42**	-0.02	1.38	0.95	11.18	2.01
SYS1:PV	2500	2061	0.495	**-6.72**	-3.10	-1.77	-2.17	8.50	-1.05
SYS3:PV	4000	3340	0.593	**-8.91**	-4.57	-1.30	-1.97	14.24	-0.50

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